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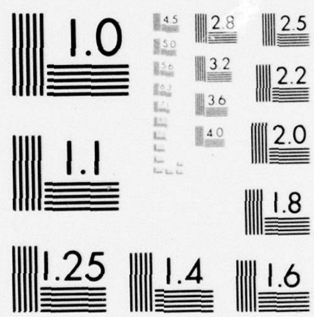

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DEFENSE SYSTEMS MANAGEMENT SCHOOL

STUDY TITLE: PARAMETRIC COST ESTIMATING

STUDY GOALS: A survey to determine the how, when, and in what manner parametric cost estimating can be used in acquisition management.

STUDY REPORT ABSTRACT

This paper is a study in parametric cost estimating or what is commonly referred to as cost estimating relationships (CERs) used in the Department of Defense. It covers the background, data collection, basic methodology and the uncertainty involved in the use of parametric type estimates. The information within has been extracted from various sources and includes the current method and means for obtaining data in addition to the uncertainty involved in parametric cost estimates.

KEY WORDS: MATERIEL ACQUISITION WEAPON SYSTEMS COST ESTIMATES CER PROGRAM MANAGEMENT

NAME, RANK, SERVICE	CLASS	DATE
Robert J. Devens, Major, USA	74-1	16 May 1974

DEFENSE SYSTEMS MANAGEMENT SCHOOL

PROGRAM MANAGEMENT COURSE
INDIVIDUAL STUDY PROGRAM

PARAMETRIC
COST ESTIMATING

Study Report
PMC 74-1

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DEVENS

PARAMETRIC

COST ESTIMATING

An Executive Summary
of a
Study Report
by

Robert J. Devens
Major USA

Defense Systems Management School
Program Management Course
Class 74-1
Fort Belvoir, Virginia 22060

EXECUTIVE SUMMARY

There is probably no problem more basic to Program Managers than cost estimating. Current decisions regarding future courses of action require good estimates. To predict new costs, different techniques and methods have been used. However, they have all shown the same common characteristic -- none has any guarantee of success.

In order to improve the overall management of Defense System Acquisition, the Department of Defense established the Defense System Acquisition Review Council (DSARC) within the Office of the Secretary of Defense. This Council was to evaluate the status and readiness of each major weapon system.

Past studies proved that weapon systems cost growth was a result of low initial estimates. In order to improve upon this, the Cost Analysis Group (CAIG) was established by the Secretary of Defense. They were to review and provide the DSARC with both program costs and ranges of uncertainty within which costs would likely be.

In addition, the Department of Defense desired that the "parametric approach" for weapon system cost estimating be used. There is no doubt that the parametric approach or as they are so often called, cost estimating relationships (CERs), can be of great use in cost estimating. Their capability to produce accurate estimates is limited and should be recognized. Viewed realistically, they are useful means of combining limited information to provide "ballpark" estimates, since in many cases they cannot capture all the variances in cost. Therefore, estimates derived by the parametric technique should be used with caution, particularly when extrapolating to distant future weapon systems.

If viewed as a point of departure, and modified by experience, judgement, and external or supplementary information, they can be used extensively with much success.

PARAMETRIC

COST ESTIMATING

STUDY REPORT

Presented to the Faculty

of the

Defense Systems Management School

in Partial Fulfillment of the

Program Management Course

Class 74-1

by

Robert J. Devens
Major USA

ACKNOWLEDGEMENT

This study is dedicated to my gracious and loving wife Lyn. She has continually managed the homefront not only during the trying times while at the DSMS but also throughout two short tours and additional periods of TDY.

CONTENTS

INTRODUCTION

During past years, the cost growth in System Acquisition has increased to such an extent that it has become the subject of national debate. With massive cost overruns in major weapons acquisition, as evidenced by mismanagement and waste, the Department of Defense decided that attention must be given to improve the management of Defense System Acquisition.

In May 1969 the Assistant Secretary of Defense, David Packard, established the Defense System Acquisition Review Council (DSARC) within the Office, Secretary of Defense. *The sole purpose* of this Council was to advise him of the status and readiness of each major system. The membership of the Council consisted of the Director, Defense Research and Engineering, and the Assistant Secretaries of Defense, Comptroller, Installation and Logistics, and System Analysis. The Council was to evaluate the status of each candidate system at the following three milestone points:

a. Program Initiation decision, i.e., when the sponsoring Service desires to initiate Contract Definition.

b. Full-Scale Development decision, i.e., when it is desired to go from Contract Definition to full-scale development and,

c. Production decision, i.e., when it is desired to transition from development to production from service deployment.

BACKGROUND

The Program Manager is caught in a vise. The programs that he is developing tend to be more innovative and more complex than past programs and, therefore, more difficult to cost accurately. At the same time the frequently casual costing concepts of the past are increasingly unacceptable to the administration, the Congress and ultimately to the people. Fortunately, presently available methods of cost analysis make it possible for the informed manager to develop and substantiate accurate projections of program costs.

Early in 1970, the Assistant Secretary of Defense for System Analysis wrote a memorandum clarifying the OSD position on the use of statistical techniques for weapon system cost estimating. This paper was circulated throughout the Army as an inclosure to a memorandum on the use of statistical techniques in cost estimating. It states that estimates for new weapon system acquisition cost were to be either derived from detailed, grass root calculations (the industrial engineering approach) or based on relationships between more aggregate components of system cost and the physical and/or performance characteristics of the system. These so called relationships were to be derived from cost histories on prior programs. This method is often called the "parametric approach." This type of estimating is used during early phases of system acquisition since many programs have limited and uncertain information on which to base estimates. The parametric approach is particularly suited to making estimates based on limited physical and performance information. The objective of parametric estimates, or as they are so often called, cost estimating relationships (CERs), is to provide for overall better program management.

The cost growth studies conducted by System Analysts showed that most of the so called cost growth was the direct result of low initial cost estimates and the indirect result of changes in schedule, quantity and rate of production.

As the cost increases, the production quantity is accordingly reduced to stay within the total program dollar thresholds. However, due to the learning curve phenomena, the reduction in quantity further increases the unit price.

A plot of the average cost growth (CHART I), as a function of time from the 34 systems now in procurement and reported in Selected Acquisition Report (SARs) shows that two years after the planning estimate was calculated, the development estimate surpassed it by 40%. In June of 1971 and December of 1972 cost growth was well over 100% on major systems. This is a factor of 2.4 to the planning estimate in terms of average growth and some growth was as high as 800 or 900%. Procurement cost growth alone increased to 450-500% and on some programs has reached the 800% mark. There is great concern over the initial low program estimates for as the Services continue to underprice the Five Year Defense Plan (FYDP), unbalanced programs result. Therefore, it is impossible to make resource tradeoffs and further purchase the right types of equipment if programs are continually under estimated. The end result is that in later segments of the program, many important components are eventually discarded.

In addition, if Services continue to increase estimates in their SARS to Congress, credibility of any correct estimate will be further lost. For example: if one of the Services arrives at a one billion dollar cost estimate, Congress will automatically think it should be two billion because of past miscalculations. Hence, the Services are left wondering whether or not to over estimate since there is no credibility with their estimates.

TIME PATTERN OF COST GROWTH

(AVERAGE FOR 34 SAR REPORTED SYSTEMS)

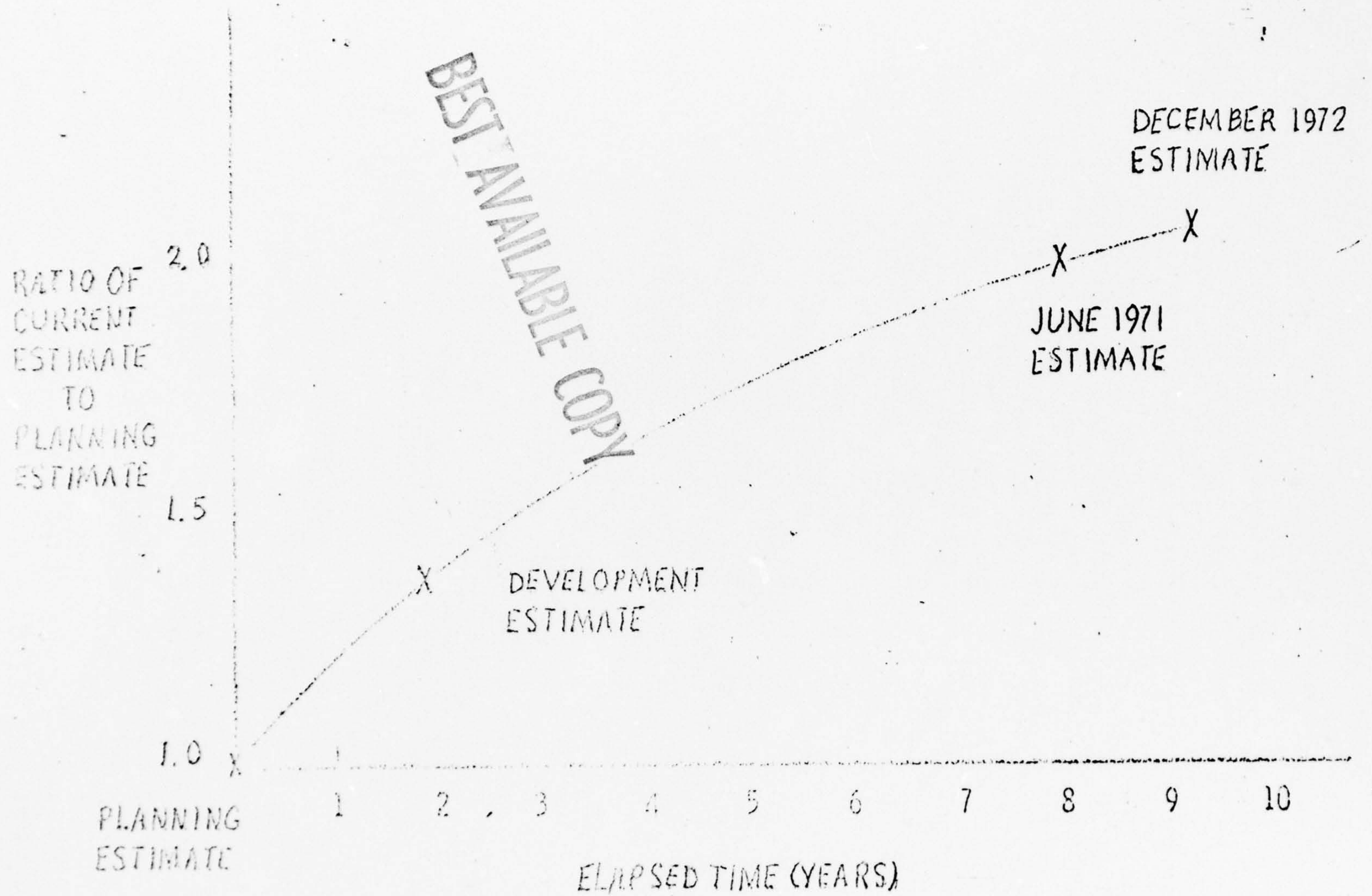


CHART 1

A STEP IN THE RIGHT DIRECTION

To counteract the previously mentioned credibility gap much more realistic estimates are needed. On December 7, 1971, the Deputy, Secretary of Defense, directed Service Secretaries to improve their capability to perform independent parametric cost analysis and to have such an analysis accomplished on each major weapon system at each key decision point. "The memorandum, Use of Parametric Estimates, advised that by January 1972 an independent cost analysis was to be incorporated in each DSARC presentation. There was a definite need for timely realistic cost estimates for DOD management. From these realistic cost estimates major decisions could be better employed."(9:2) Chart 2 depicts the sequence of independent cost review for DSARCS.

Past cost estimates were usually based on the industrial engineering approach whereby extensive system descriptions and design were required in addition to a detailed simulation of production operations. This approach previously mentioned as the "grass roots" approach used standards built from time studies, motion studies, vendor quotes, etc.

Because of incorrect cost estimates, program consequence included:

a. A choice of higher performance designs than were cost effective.

b. Many attractive alternatives were foregone.

c. Cost growth was destroying the budget by stretch-outs and fewer more expensive units.

d. DOD credibility was reduced, and

e. Overall management became difficult.

Another approach to cost estimation was needed if the acquisition

SEQUENCE OF INDEPENDENT COST REVIEW FOR DSARCs

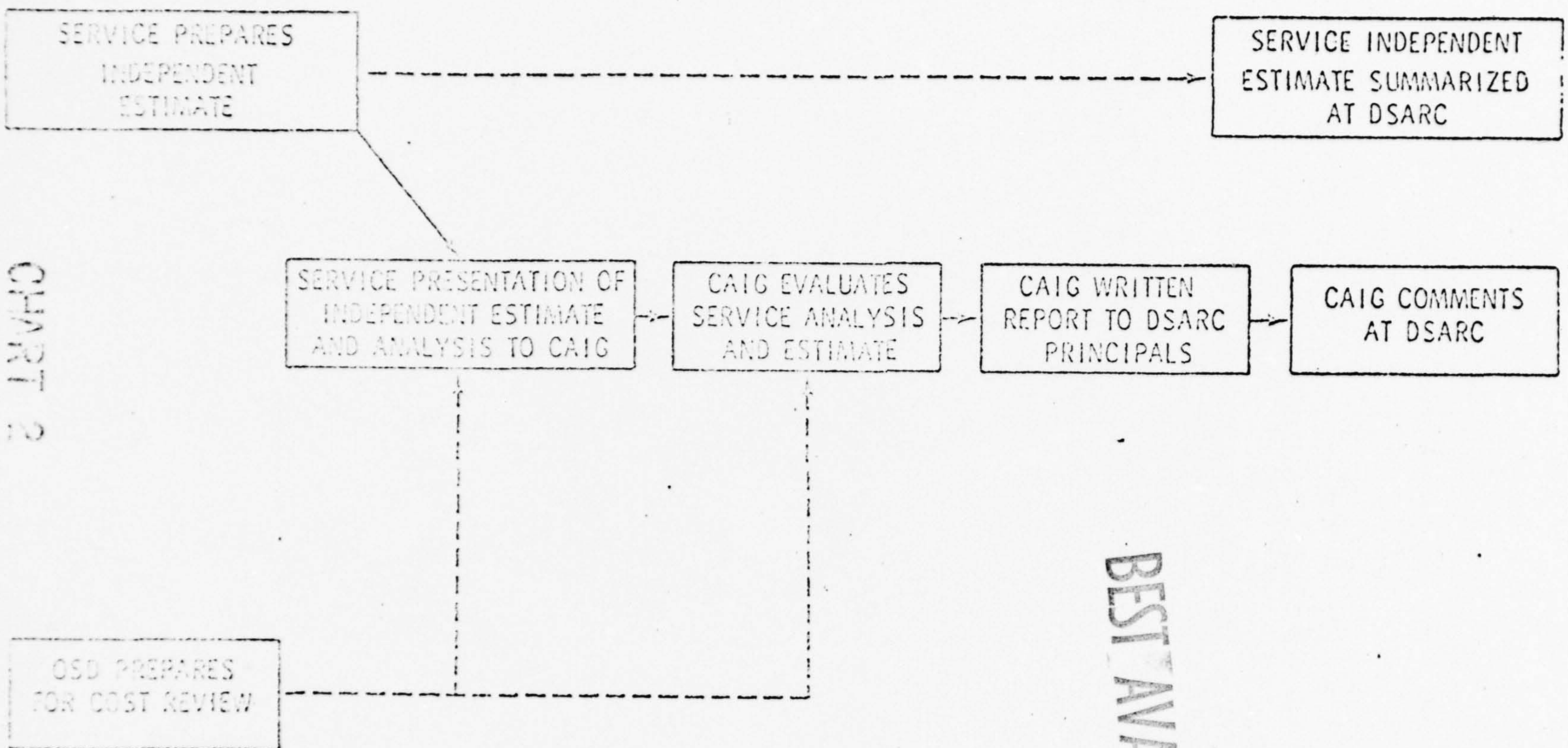


CHART 2

of major weapon systems was to survive. As a check to the "grass roots" approach, DOD decided to place increased emphasis on parametric cost estimates. These estimates were to incorporate costs of previous system setbacks and present aggregate level estimates. They included actual relationships between cost and physical performance characteristics of past systems.

In a memorandum dated 25 January 1972, Secretary of Defense Melvin Laird established the OSD Cost Analysis Improvement Group (CAIG) to act as an advisory board to the DSARC on all matters related to cost. Members of this group included representatives from DDR&E, ASD(C), ASD(I&L) and ASD(SA). The CAIG was directed to review service's independent estimates and report any resemblance of the cost estimate. Service Secretaries were encouraged to provide staff components capable of providing independent parametric cost estimates (ICE).

With this CAIG cost data report the DSARC could compare Contractor, Service and OSD program costs as illustrated on Chart 3. The DSARC not only was provided with a point estimate of most likely cost, but a range of uncertainty within which the cost would likely be. This range of uncertainty shown on Chart 4 is necessary because all cost estimates are only predictions, and, therefore, contain some degree of uncertainty.

Chart 5 illustrates the ratio of CAIG cost estimates to those of Service independent studies and accepted by CAIG. It would appear by this chart that the CAIG cost estimates are significantly higher than those of the Services. Therefore, analysis of this has proven that during the past few years the CAIG estimate has been closer to the actual cost of military programs, whereas the Service estimates have been far below. Chart 6 clearly substantiates this and further indicates that costs which are reported to Congress in the SARs are beginning to approach the parametric cost previously estimated by the CAIG.

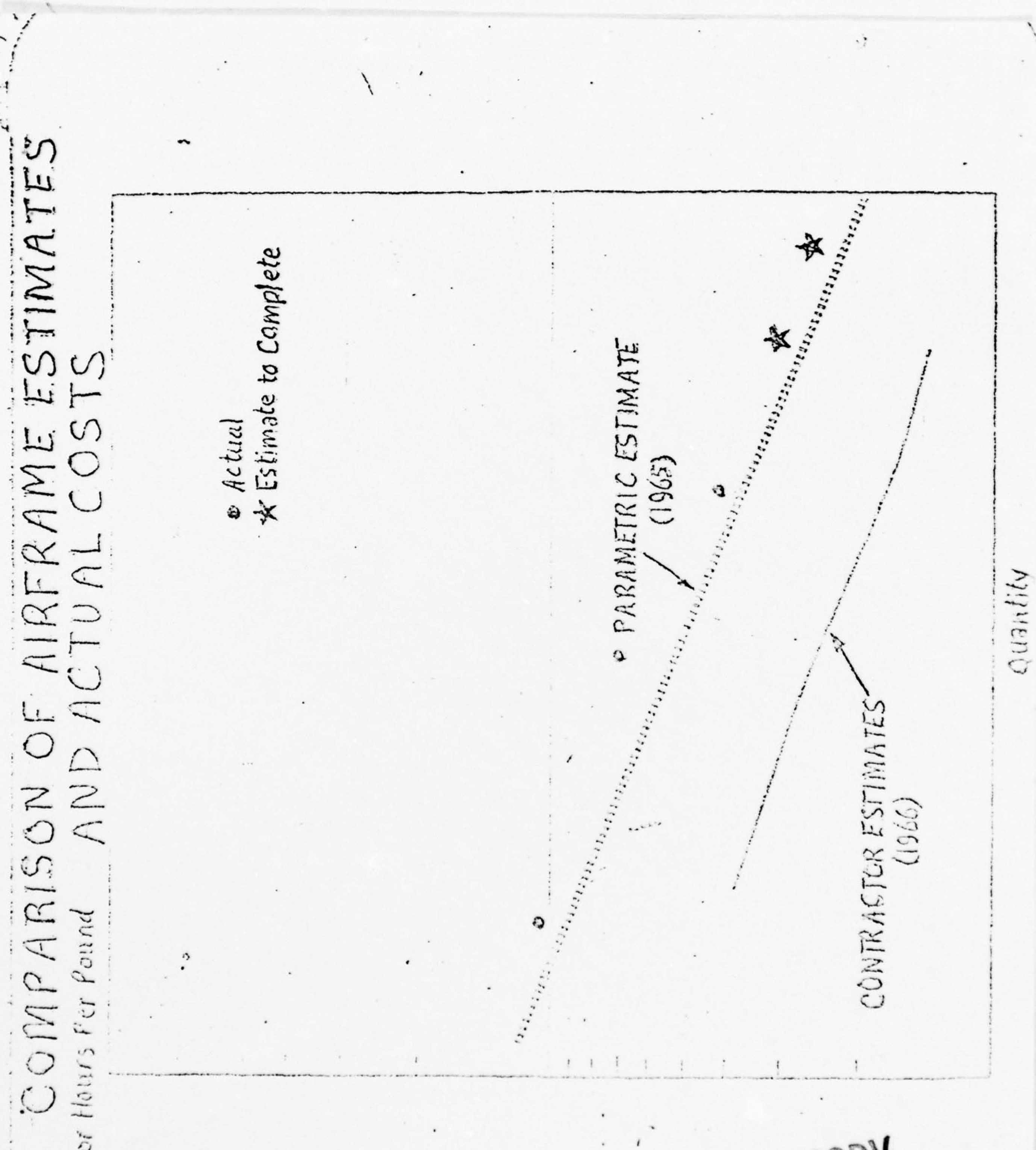
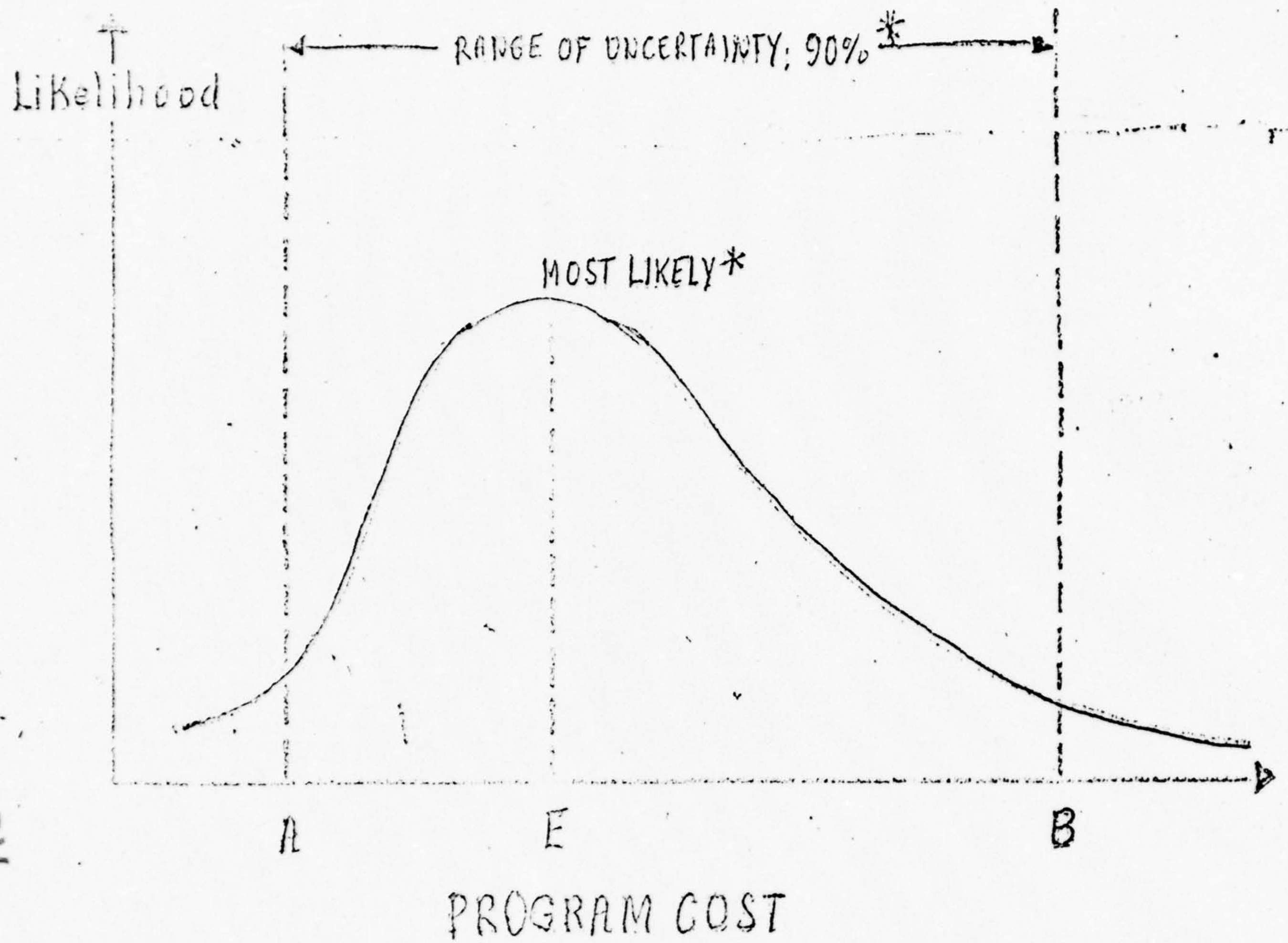

COMPARISON OF AIRFRAME ESTIMATES
AND ACTUAL COSTS
Labor Hours Per Pound
Actual
Estimate to Complete
PARAMETRIC ESTIMATE
(1965)
CONTRACTOR ESTIMATES
(1966)
Quantity

CHART 3

PROGRAM COST PROJECTION



*CAIG REPORTS PROVIDE TOTAL PROGRAM AND NEXT PHASE COSTS IN THIS FORM WHENEVER POSSIBLE

CHART 4

RATIO OF CAIG TO PROGRAM OFFICE

Procurement Cost Estimate

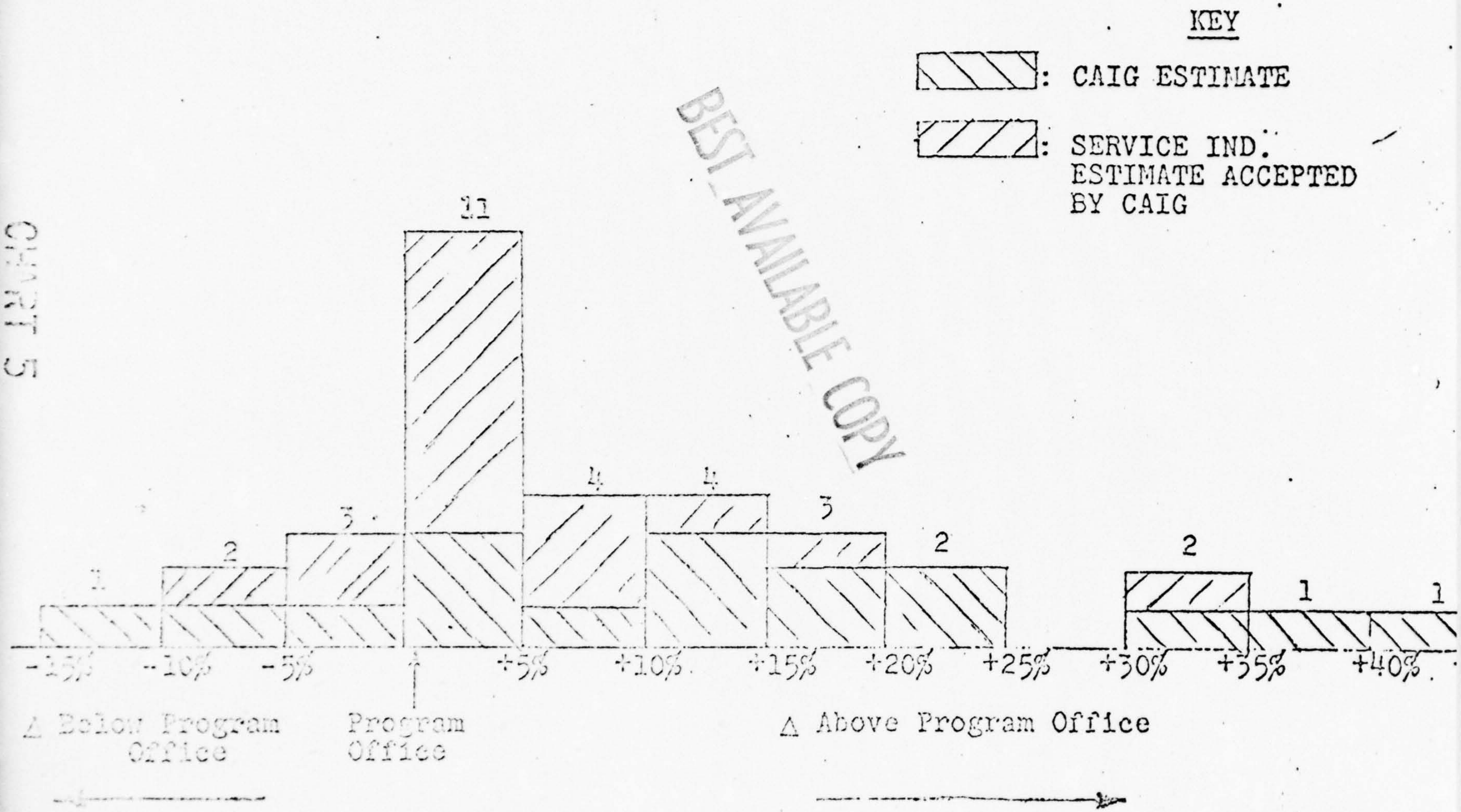


CHART 5

FOR OFFICIAL USE ONLY

PROGRAM COST HISTORY

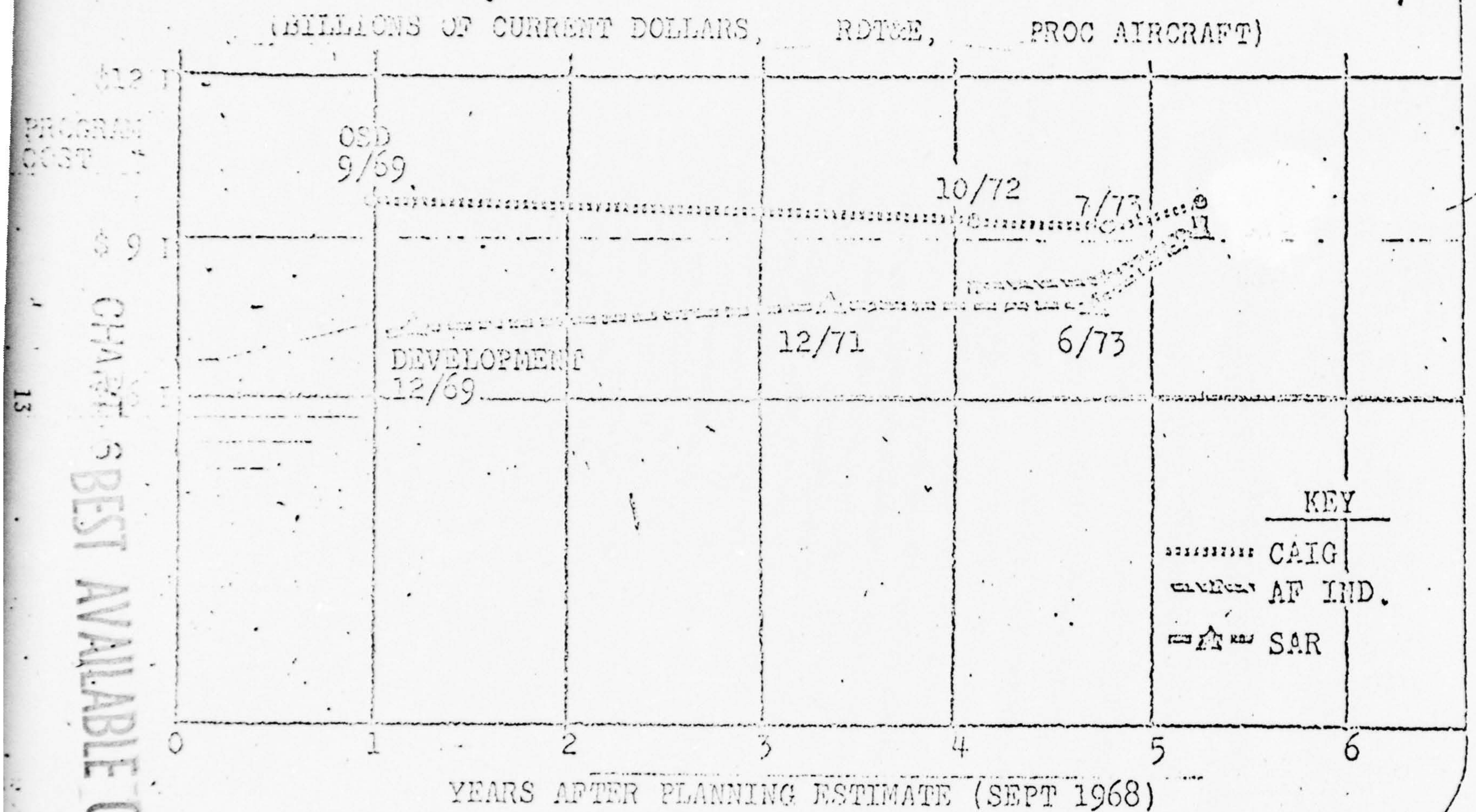


CHART 6

DATA COLLECTION

As previously stated, a cost estimate is a judgement or opinion regarding the cost of an object, commodity, or service. "The main problem facing the military cost analyst is to develop and apply concepts and techniques for assessing the economic cost of proposed alternative future actions under conditions of uncertainty." (1:64) The challenge is to project from the known to unknown relationships, using explanatory variables such as weight, speed, power, frequency and thrust to predict cost at a higher level of aggregation.

Parametric cost estimates have proven to take less time and have been more accurate than the industrial engineering process. "One reason for this is simply that the whole generally turns out to be greater than the sum of its parts." (3:33) This method involves the use of quantitative techniques which are reproducable. Thus, a given technique, although perhaps not optimum, will always give an estimate that will not vary with the particular person using the estimate. This process involves locating physical or program characteristics that have a definite relationship to cost. These relationships are simple statements indicating that the cost of a commodity is proportional to the weight, volume, area, or some other physical characteristic of that commodity. The cost estimating relationship may also be indirectly determined such as the number of various size uniforms required would be a function of the number of personnel. For proper development and evaluation of cost estimating relationships, some familiarity with regression theory is necessary. However, it must be emphasized that

that regression analysis does not offer a quick and easy solution to all the problems of estimating cost. There is no substitute for understanding! The important element is to identify variables so that when weighed and combined in appropriate mathmatical expressions, an accurate cost estimate will result.

In order to provide an accurate estimate, a requirement for a systematic collection of data and information is a prerequisite. Military cost analysts are no better than the information or data that are part of their analytical effort. Due to inconsistency in data, the analyst has had to use contractors records in the past. To alleviate this problem, the Cost Information Report (CIR), was established in 1966.

Even with the use of the CIR much inconcistency was found in the data which it provided. The result was the Contractor Cost Data Report (CCDR), a new requirement of the CAIG which further standardized both data and format reporting. "This report provided for collecting projected and actual cost data on acquisition programs from contractors and in-house government plants through a single integrated system for DOD cost analysis and procurement management purposes. The CAIG was to provide guidance and monitor the implementation of these reports to insure consistent and appropriate application throughout the DOD." (;1)

Actual test of the CCDR was to be implemented on the Trident Program. It might be interesting to note that the PM requested this be waived but it was denied by the CAIG.

THE LEARNING CURVE

Learning curves are a special application of cost estimating relationships. They are a graphical/mathmatical way of expressing the process of learning or improving as a worker completes a repetitive task. This concept of learning curves is based upon the emperically observed relationship that, given a constant production environment the cumulative production output varies inversely with the manhour input labor. The basic use for this type of estimating is to forecast the unit price of an item or system over its production life.

Both Industry and Government have found that the unit cost of producing hardware decreases as the cumulative production quantity increases. To quantify this relationship, the learning curve is used. The application of such a curve as the learning or progress curve is relevant to only the recurring portion of production costs and measures true learning only when all recurring costs are converted to constant dollars.

> While there are several different hypotheses about the exact manner in which this learning or cost reduction occurs, the main content of learning curve theory is that each time the total quantity of items is produced doubles, the cost per item is reduced to some constant percentage of its previous value. If, for example, the cost of producing the 200th unit of an item is 80 percent of the cost of producing the 100th item, the cost of the 400th unit is 80 percent of of the cost of 200th, and so forth, then the production process is said to follow an 80 percent unit learning curve. If the average cost of producing all 200 units is 80 percent of the average of producing the first 100 units, etc., then the process follows an 80 percent cumulative average learning curve. (3:84)

The two most familiar forms of learning curves assume that as the cumulative production quantity of units doubles the cost per unit declines by some constant percentage. One form treats the cost as the incremental or unit costs; the other treats it as the average cost for the cumulative number of units. Either formulation results in a function that is linear when plotted on logarithmic grids. When the incremental cost assumption is made, the form of the learning curve is termed the "log-linear unit curve", when the average cost assumption is made, it is known as the "log-linear cumulative average curve."

There are not inherent advantages in one form of the learning curve as opposed to the other. Where it is possible to use either form, the one that best fits the data should be used. Sometimes, however, this option may not be open because of the nature of the available data.

One authority has suggested that experienced manufacturers and/or manufacturers starting production with major engineering problems well under control are likely to produce along a log-linear unit learning curve. It is further suggested that new manufacturers and/or those beginning production with a large number of engineering problems unsolved are likely to produce along a log-linear cumulative average learning curve.

The Log-Linear Unit Curve. The algebraic expression for the log-linear unit curve is:

$$Y_i' = aX_i^b$$

where Y_i = cost of i^{th} unit

a = cost of first unit

X_i = cumulative unit number

b = slope parameter

The parameters a and b may be estimated directly by regression analysis if several values of Y and related values of X are known. However, this is usually not the case. Costs of hardware items are almost always accounted for in "lots" rather than in single units, and the average unit cost of a lot is not the cost at the arithmetic mean of the lot units. For example, if a lot includes cumulative quantities 101 through 200 at an average unit cost of $100, then the cost of unit 150 is not $100. This is because learning occurs within the lot itself.

Most methods of obtaining a match of cost to unit number involve estimating the unit number (the algebraic mid-point) for which the average lot cost is applicable. One method involves the use of tables from which the algebraic mid-point may be calculated for a known range of unit numbers in the lot and an estimate of the learning curve slope. This, of course, requires an iterative process if subsequent regression analysis shows that the slope estimate was incorrect.

DERIVATION OF CERs

In the derivation of cost estimating relationships, certain steps should be followed: The first is the consideration of the various factors that may cause a given result. The actual determination of causes and effects of past experiences has to be ascertained. The next step is to gather data, locate interdependencies, derive a formal statement of the relationship and establish the limitations of this particular relationship. This is considered one of the most critical steps in parametric cost estimating, for it is in collecting the data that an accurate mathmatical expression can be developed or lost. By careful examination of this data, unexpected cost estimates may even develop.

Cost analysts are using regression theory more and more in developing cost estimating relationships. In regression analysis the value of one variable is based on its relationships with another. The theory of regression examines whether a relationship exists and when it does the nature and extent of the relationship is measured.

Therefore, the essence of the regression analysis is that functional relationships between cost and explanatory variables is direct and obvious. A pattern has to be established in analyzing what variables can be logically related to cost. Many systems today seek to find a direct relationship with weight and cost. However, a close analysis of various systems will show this is not always possible.

The overall estimate must have the following characteristics:

a. an unbiased estimate - the weights arrived by the process of regression should truely represent the relation of that variable to the total cost. Since the collection of all sample data is impossible, there will naturally be some bias in the weights.

b. an efficient estimate - the smallest variance in a sample would be the result of examining all the possible values of that variable, but to the extent that this is impossible, the estimate will be inefficient.

c. a consistent estimate - again this is a problem of sample size in that the larger the original data base, the more consistent will be the estimates.

d. a sufficient estimate - no other group of variables weighed in some other way would give a better estimate.

USE OF PARAMETRIC ESTIMATING (CER)

At this point the concept of parametric estimating as it is used in the Army (ECOM) will be introduced. This section describes a CER for digital computers developed by the Electronic Command (ECOM) located at Fort Monmouth, New Jersey. ECOM is responsible for managing the entire life cycle development, procurement, and fielding of tactical communication, avionics, radar, automatic data processing, meterology, night vision, combat surveillance, target acquisition, navigation and electronic warfare equipment and systems.

The ECOM digital computer CER was composed of commercial third generation general purpose computers, ranging in capacity from small to large. In the derivation of cost data ECOM found much inconsistency although their statistical methodology was correct. Appropriate cost adjustments were made and additional computer characteristics were calculated and two statistically significant CERs were derived for predicting the acquisition cost of a digital computer: one based on a sample of 11 computers and the other based on the same 11 computers with two different core storage sizes for each, i.e., a sample size of 22.

POPULATION DEFINITION

The two CERs based on the acquisition cost of the central processing unit with floating-point arithmetic, console, and core storage of commercial general purpose third-generation computers ranging in size from small to large scale.

DATA COLLECTION, ANALYSIS, AND ADJUSTMENT

The first step which ECOM assumed was to list all variables that they expect would be closely related to cost. These variables included everything from weight to actual volume size of components. After gathering this large volume of data they searched for variable interdependencies with cost. The following variables were considered pertinent and hence they were collected for each computer.

1. fixed point add time
2. words of core storage (in terms of bits by multiplying number of words by bits per word. This makes core storage comparable among computers with different word sizes.
3. bits per word (calculated by dividing cycle time into total number of bits accessed per memory cycle. This places computer that access different numbers of bits per memory cycle on a more comparable basis)
4. memory cycle time
5. number of operation codes

PRELIMINARY ANALYSIS

During their next step in seeking to establish a relationship in order to develop a mathmetical expression, a graphical analysis of cost vs core storage size indicated that these were linearly related, though not sufficient to produce a satisfactory CER.

By examining values of other characteristics and relating these to the cost differences not accounted for by the core size (e.g., projected costs of computers with one million bits of storage) it appeared that inclusion of two additional characteristics-bits per memory cycle and fixed-point add time-would result in an improved relations. (variables 1, 3 & 4 above)

Algebraic expressions were formulated using these three variables, and regressions were run on an ECOM computer. Next, analyst tried different combinations of the variables (both linear and log-linear) to see which one gave the best predictions based on past data. The best results were obtained with the linear formulation of core storage, bits per memory cycle time, and the reciprocal of fixed-point add time. It may be noted that linear formulations usually present the best results.

CER RESULTS

The CERs developed are given below. The first CER is based on one core storage size for each computer:

$$C = 105 + 2.90\ A + .157\ S + 709\ \left(\frac{1}{T_2}\right) \qquad \text{I}$$

where C = costs in thousands of dollars

A = number of bits accessed per memory cycle time (bits per microsec)

S = core storage size (thousands of bits)

T_2 = fixed-point add time (microseconds)

and $R^2 = .96$

standard error of estimate = 84,

F ratio = 28.6

Sample size = 11

The second CER is based on two core storage sizes for each computer:

$$C = 93 + 3.38\ A + .153 + 698\ (\frac{1}{T}) \qquad \text{II}$$

where the variables are defined as earlier,

and $R^2 = .97$

Standard error of estimate = 90

F ratio = 108.8

Sample size = 22

The reasons for selecting this as best is that R^2 has the highest value. R^2 being defined as the coefficient of determination of the variables.

Although Eqs. I and II are statistically valid, they apply only to computer technology as of about 1965. Since that time many advances have been made that have the effect of increasing performance for a given price or decreasing price for a given performance value or core storage size.

A possible approach to developing CERs that could be used for predicting future computer costs would be to analyze cost and characteristic data representing computers over several years and technologies. This would add more data points than was possible during the current effort.

COST ESTIMATING COMPARISONS

The two main categories of estimating are judgemental and scientific estimating. In judgemental estimating, the estimates are made subjectively with or without an explicit procedure on the basis of intuition, experience, and common sense. The distinguishing feature of judgemental estimating is its lack of uniformity as the estimates vary with the estimator. This is not to say, however, that judgemental estimations will provide results inferior to those produced by other methods. A common sense estimate or intuitive guess by an expert may be the best possible (or luckiest) estimate. Scientific estimating is sometimes categorized into time series (projection) and parametric models.

In the time series estimating method, the emphasis is on pattern and pattern changes, and the method thus relies entirely on historical data. Parametric estimating on the other hand, seeks to develop relationships among system elements by using refined and specific relationships, thereby, being powerful enough to take special events favorably into account. No one has ever constructed a parametric model that can guarantee success, except on a probabilistic basis.

The time series analysis and projection type of estimate cover many different methods and techniques. The basic thrust of all of these methods is that they attempt to extrapolate the behavior of a time series by relying wholly on past data and not searching for any parametric agents. Because of this, time series methods are sometimes called naive. One of the more well known time series methods of estimating is Curve Fitting.

This method is the simplest and most commonly used method of time series analysis. The objective of curve fitting is to select an analytical model that fits the time series fairly well. In general, the model contains parameters that are unknown and must be selected such as to give a "best" fit, where "best" is a specified condition.

There is no doubt that parametric (CER) or what is referred to as regression analysis can be put to great use in cost estimating. However, CERs do have limitations which, along with their advantages, should be recognized. CERs cannot capture all of the variances in cost, therefore, they can provide only a ballpark figure.

Advantages of CERs include:

a. Less expensive to obtain than "grass roots" estimates for any relatively large or complex system.

b. Statistics related to the CER give some indication of the credence to be placed on the estimate. Summary figures of merit are more difficult to generate for the industrial engineering estimate.

c. A CER is a relatively objective method of estimating costs compared to estimating by analogy.

d. The CER approach is a more sensitive method of estimating than the analogy approach in that the former is based on an "average" of several observations.

e. Statistics related to a CER give a viewer some indication of the merit of the CER.

Disadvantages of CERs include:

a. Since industrial engineering estimates are based on specific production process and materials, it seems reasonable to expect the industrial engineering approach to produce more accurate results than the CER. Although it is possible to use both types of estimates, parametric is about all that is available during the Conceptual and Validation phase, since there isn't much data available. However, once the Full-Scale Development phase commences, grass roots estimates can be made using the data within the Work Breakdown Structure (WBS) packages.

b. When a system has few or no historical counterparts it may not be a practical alternative to use CERs.

c. In comparison to the analogy approach which involves the relation of cost to a single variable, the CER approach requires collection of data from several predecessors.

d. Although data on earlier items or systems may have once been readily available, the data may have later been destroyed in such a manner as to be virtually unobtainable.

e. Data might be available but only at very high costs.

UNCERTAINTY

"Uncertainty relates to those phenomena which create variability and cannot be insured against by adding to costs." (6:1) It is the result of a subject reasoning process and refers to the unspecification of a certain degree of ignorance.

The difference between original estimates and final costs of weapon systems have been so great that as of late, agencies have been looking into various case histories in an attempt to identify reasons for cost overruns. These efforts were certainly justified as the increase in cost for various systems are considerable. For example, the factor increase in fighter aircraft ranged from "on cost" to 3.9. Bombers ranged to 6.2, cargo aircraft were less prone to overrun with a factor of 1.5 and missiles depicted a wide variation which ranged to 14.7

The main point of interest in these overruns is the reasons for the increases and whether the increases are due to bad or incorrect cost estimating.

Studies have concluded that the main reason for the above increases was due to cost estimating uncertainty. This refers to variations in cost estimates of a system for which the configuration is essentially fixed. Specifically, the factors associated with uncertainty are:

a. Errors in cost-estimating relationships.

b. Errors in data.

c. Extrapolation errors.

Some examples of uncertainty include:

a. Origin, time, and extent of future threats to our national security.

b. Capability of a particular weapon system to meet a threat with regard to equipment performance, reliability, and operation.

c. Capability of cost analysis to translate the design of the weapon system into a statement of resource requirements and costs.

Proposals for treatment of uncertainty in cost analysis range from conventional statistical tools to the application of what are commonly known as "fudge factors." The latter is ruled out because of a high sense of morality that states that fudge factors are wrong.

Conventional statistical tools, are of only limited value in coping with uncertainty in cost analysis because of the occasions for which they can be used rigoriously are quite rate. Even in these cases, we may still have problems because of difficulty in justifying the assumptions of the statistical model in our particular application.

Finally, where conventional statistical methods are applicable, it is most likely to be in the treatment of cost-estimating uncertainty rather than requirements uncertainty which is the more important of the two.

One of the most useful tools for dealing with uncertainty is the technique of Cost Sensitivity Analysis. The primary objective of this type of analysis is to provide a system designer or a planner with insights into the way system costs are influenced by changes in assumptions and specifications. The Cost Sensitivity Analysis appears promising because it highlights the uncertainty inherent in future system costs and gives the planner a full view of the cost implications on decisions affecting system configuration and operations. In general, this type analysis is the process of examining how total system resource requirements or costs change as key system characteristics are varied over a relevant range. A cost analyst can point out where costs are relatively sensitive, discover ranges of values within which costs do not change significantly and outside of which costs rise sharply, and provide some meaningful answers to problems by using the Cost Sensitivity Analysis Technique.

Another technique of dealing with uncertainty is the use of the judgemental forecast called the Delphi Method. Here a panel of experts is interrogated with a sequency of questions (or questionnaires) to which the next question (or questionnaires) is based upon the previous response. Thus, all the experts are given access to all the information for forecasting. This method proports to minimize the "bandwagon effect" of public opinion.

Another method for dealing with uncertainty begins with the assumption that a cost analyst can describe each input parameter with a probability distribution. This distribution is then treated as a theoretical population from which random samples are obtained. The methods of taking such samples, as well as problems associated with these techniques are referred to as the "Monte Carlo" Method.

> The Monte Carlo technique involves constructing a cumulative probability distribution from the probability distribution describing the actual or estimated input uncertainty. Next, a random decimal between zero and one is selected from a table of random digits. As presented in Chart 7, by projecting horizontally from the point on the Y-axis corresponding to the random decimal to the cumulative curve, we find the

value of x corresponding to the point of intersection. This value is taken as a sample of the value of x, the input parameter. The result, if this procedure is repeated numberous times, is a sample of imput value that approximates the required uncertainty. (6:5)

It must be remembered while preparing any cost estimations there is always an end to available data. However, in many instances there is a need to go beyond the data base and extrapolate further. When this is done our confidence decreases (uncertainty increases as illustrated in Chart 8). This illustrates how additional cost-estimating arises when we are forced beyond the data base.

In summary, cost analysis of future military capabilities are subject to both state-of-the-world uncertainties as well as statistical uncertainties.

MONTE CARLO SAMPLING

INPUT UNCERTAINTY   CUMULATIVE DISTRIBUTION

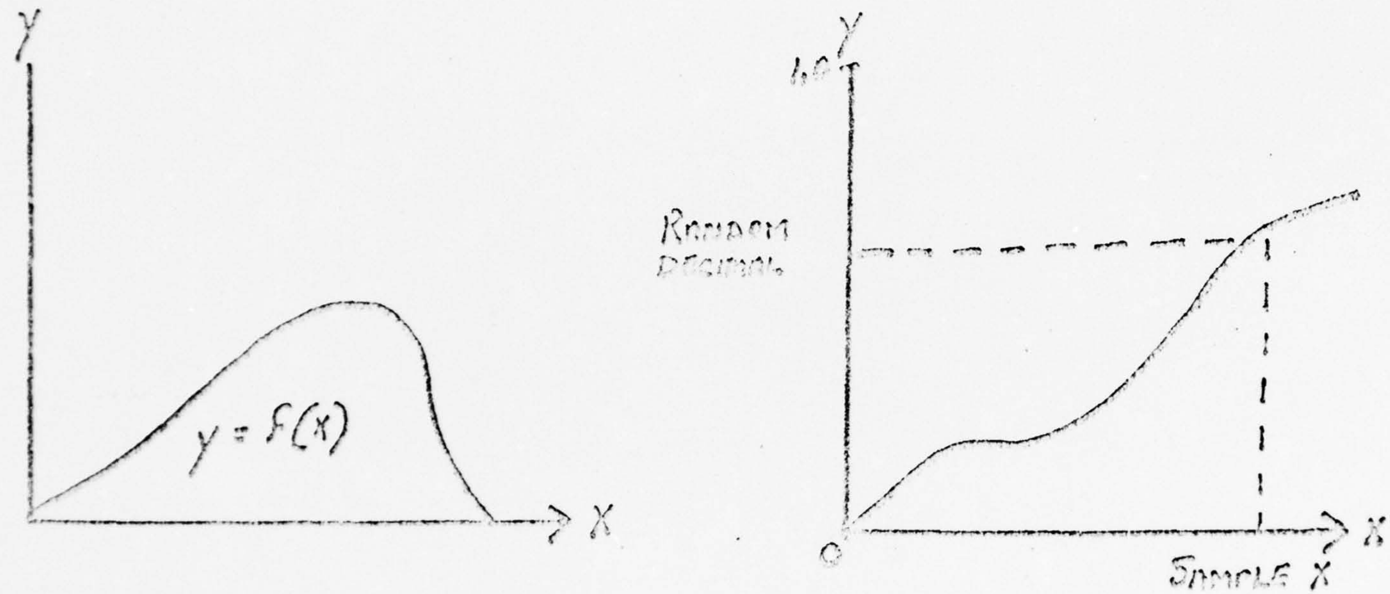


CHART 7

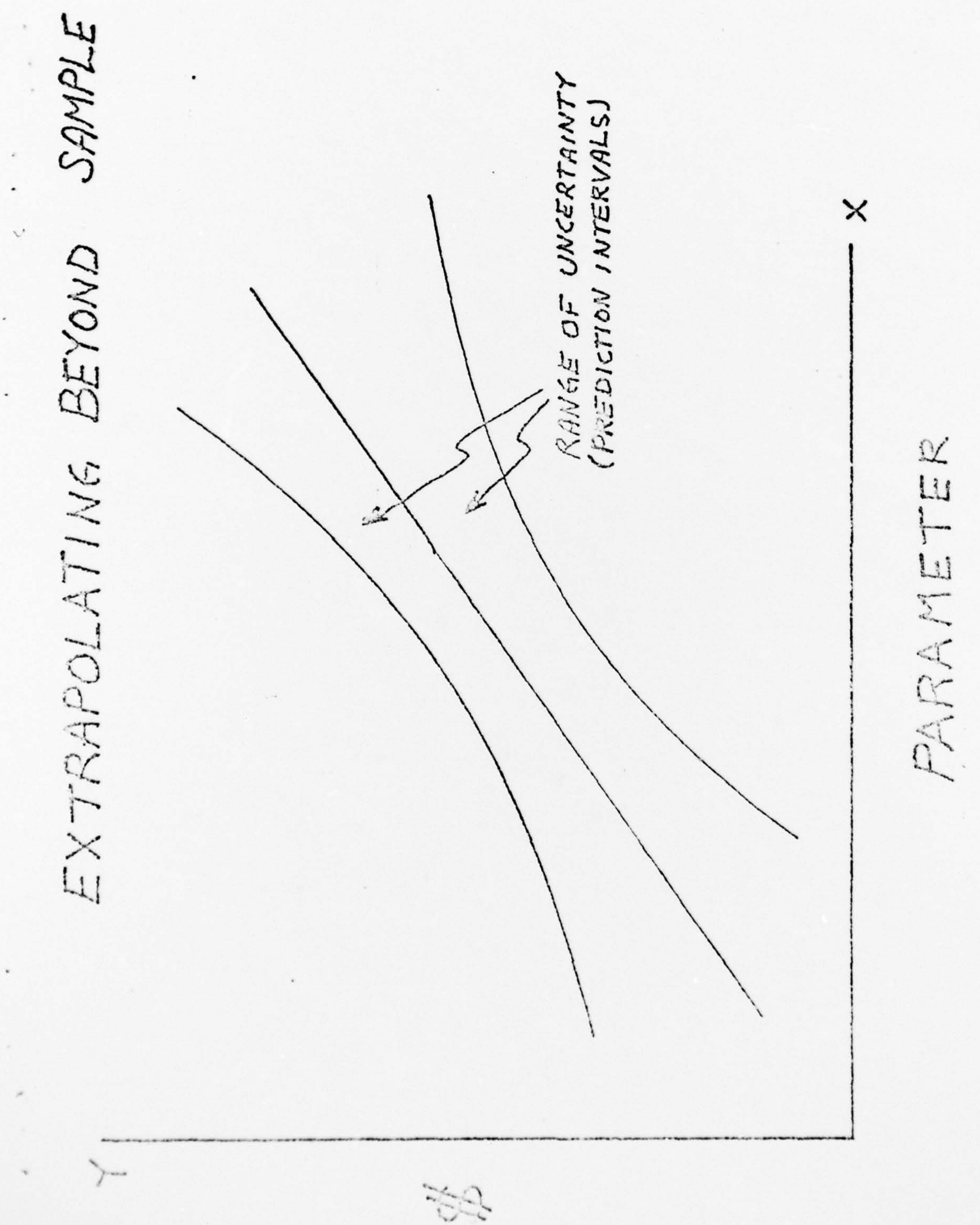

EXTRAPOLATING BEYOND SAMPLE
RANGE OF UNCERTAINTY
(PREDICTION INTERVALS)
X
Y
PARAMETER

CHART 8

SUMMARY/CONCLUSION

Although cost overruns have occurred for centuries (e.g., a Roman aqueduct cost more than twice the original estimate), they are exclusive to neither government nor military and are not limited to projects advancing the state of the art. There is a definite need for these excesses within the acquisition of major systems in the military services to be reduced in scope. This is to be accomplished by primarily improving the process of acquiring major weapon systems. The acquisition process has been the subject of analysis and police recommendations for years, yet evidence of improvement is only noticeable during the past few years.

It seems that cost growth is directly related to and the result of adjustments in target goals. Although adjustments are a necessity in many instances, they should be held to a minimum. Research has indicated the need for a continuing effort to control the cost, schedule, and performance outcome of programs and for better understanding of the causes of program cost growth.

System acquisition policy should be flexible but based on incremental acquisition strategies as the normal approach for the 1970s. In particular, development should be separated from subsequent production, and the initial portion of development should concentrate on demonstrating system performance and be conducted in a healthy austere fashion.

It is believed that the methods used in parametric cost estimating are a sensible way of using an imperfect information about the past to decrease the uncertainties about future weapons cost. Parametric cost analysis or what is commonly referred to as regression analysis involves finding physical or program characteristics that have a relationship to cost. Such relationships could include weight, speed, power and its impact upon cost.

Further, one of the most effective ways to strengthen cost controls is to reduce the task uncertainty associated with cost estimating.

In conclusion it must be remembered that estimating cost relationships are very complex and while statistical analysis can aid in providing a understanding of factors which influence cost, parametric analysis does not solve all problems in cost growth. The use of cost estimating relationships should be utilized as an aid, to be supplemented by experience, judgement and other types of information.

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